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EQUIPMENT AND METHODS FOR MEASUREMENTS OF SOIL TEMPERATURE

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Soil and Water Conservation Research Division
Agricultural Research Service
United States Department of Agriculture
in cooperation with the
Agronomy and Agricultural Engineering Departments
Iowa State College of Agriculture and Mechanic Arts

EQUIPMENT AND METHODS FOR MEASUREMENT OF SOIL TEMPERATURE

by W. E. Larson, W. C. Burrows, and T. E. Hazen[1/]

Crop production research workers are increasingly recognizing the need for more information on soil temperature. Management practices for tillage, drainage, and residue can influence soil temperature materially and hence by this means as well as others have an influence on crop growth. The increased use of agricultural chemicals such as anhydrous and liquid ammonia fertilizers, herbicides, and soil insecticides has made necessary a better knowledge of soil temperature and the factors affecting it.

A number of types of soil temperature measuring devices are being used for routine determinations. Three types of instruments have been used extensively in soil-tillage studies in Iowa. The three types are mercury-in-glass thermometers, bimetal dial thermometers, and multiple-point recording potentiometers using copper-constantan thermocouples in combination with a switching device capable of recording up to 320 separate temperatures in 1 cycle.

It is the purpose of Part I of this report: (a) To present information on the accuracy and suitability of mercury-in-glass thermometers, bimetal dial thermometers, and thermocouples together with the multiple-point recorder, for routine field determinations of soil temperature; (b) To show the relationship of daily maximum and minimum soil temperatures at various depths to soil temperatures at certain times of the day. Part II will describe the construction of the switching mechanism that is used with the multiple-point recorder.

[1/] Larson and Burrows are Soil Scientists, Soil and Water Conservation Research Division, ARS, USDA; Hazen is Associate Professor of Agricultural Engineering, Iowa State College, Ames.

PART I. MEASUREMENT OF SOIL TEMPERATURE AND ESTIMATION OF MAXIMUM AND MINIMUM SOIL TEMPERATURE

Equipment

The mercury-in-glass thermometers were ordinary laboratory thermometers obtained from a laboratory supply house. The scale was -30° to +120° F. Hamid and Shaw (1)[2] tested the suitability of mercury-in-glass thermometers for soil temperature measurements and concluded that at depths below 1-inch the error in measurement was 1° or less.

The bimetal dial thermometers[3] have a coil-within-coil structure about 1 1/2 inches long located in the end of a hollow stem. Changes in temperature cause a rotary action of the bimetal helix; this turns a shaft on which a pointer is mounted. The instruments used in this study employed three indicators. One indicated the current temperature, a second the maximum temperature, and a third the minimum temperature. The thermometers can be purchased with different stem lengths for different soil depths. Van Bavel and Forrest (5) concluded that these thermometers were accurate to less than 1° F., were easy to read, and could withstand normal field exposure.

The multiple-point recording potentiometer using copper-constantan thermocouples consisted of a commercial 16-point strip chart recorder together with a locally constructed multiple switching mechanism allowing up to 320 temperatures to be printed on paper within less than 10 minutes. In this study a timer was employed so that soil temperatures could be recorded once each hour. (Details of the construction and use of the unit are given in Part II of this report.)

Hereafter in this report the mercury-in-glass thermometers, the bimetal dial thermometers, and the multiple-point recording potentiometer units will be referred to as glass thermometers, dial thermometers, and the thermocouple recorder (or thermocouples, thermocouple recorder points), respectively.

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[2] Numbers in parentheses refer to Literature Cited, page 32.

[3] Manufactured by Weston Electrical Instrument Company, Newark 5, N.J. The approximate cost was $20 each. This information does not constitute endorsement of the instrument nor deny the superiority of other makes.

Methods and Accuracy of Results

The accuracy of the glass thermometers, dial thermometers, and the thermocouple recorder was established by calibration against a high-grade mercury-in-glass thermometer in a water bath. Twenty glass thermometers, 20 dial thermometers, and a total of 128 thermocouples attached to the recorder were placed in the water bath along with the standard glass thermometer; and temperatures were read over the range 41° to 106° F. The temperature of the water in the bath was controlled to within 0.1°. The temperature of the standard, the average reading of the 20 glass thermometers, the average of the 20 dial thermometers, and the average of 20 randomly selected temperatures from the 128 recorder points together with the standard error of the mean for each instrument at each temperature are given in Table 1.

Table 1. Average temperature and standard deviation of 20 glass thermometers, 20 dial thermometers, and 20 thermocouple recorder points together with the standard temperature, as measured in a water bath

Standard thermometer	Glass thermometers	Dial thermometers	Thermocouple recorder
	Degrees F.		
41.2	41.2(±0.3)	40.6(±0.7)	39.8(±0.2)
45.0	44.9(±0.2)	43.3(±0.8)	43.4(±0.1)
49.3	49.2(±0.3)	48.9(±0.8)	48.1(±0.1)
53.8	54.0(±0.2)	53.3(±0.2)	52.5(±0.2)
53.9	54.1(±0.3)	53.5(±0.8)	52.9(±0.2)
61.9	62.0(±0.2)	61.1(±0.6)	60.8(±0.3)
73.4	73.1(±0.2)	72.1(±0.7)	72.1(±0.3)
81.5	82.1(±0.3)	81.4(±0.8)	81.4(±0.1)
82.3	82.1(±0.1)	81.5(±0.8)	81.5(±0.2)
85.9	85.7(±0.3)	84.6(±0.5)	84.7(±0.3)
87.7	87.0(±0.2)	86.6(±0.9)	87.1(±0.2)
95.0	94.8(±0.3)	94.4(±0.8)	94.6(±0.2)
106.0	105.9(±0.3)	105.5(±0.8)	106.6(±0.2)

Average temperature readings of the 20 glass thermometers usually were within 0.2° F. of the standard over the range 41° to 106°. The standard deviation between thermometer readings was about 0.3°. The regression of the standard temperatures (S) on the mean glass thermometer reading (G) was $S = -0.2 + 1.003\,G$.

The average temperature reading of the dial thermometers was generally lower than that of the standard thermometer. The regression of the standard temperature (S) on the average dial thermometer reading (D) was $S = 0.6 + 1.001\,D$. The standard deviation was about 0.8° F., which indicates that there was considerable variation among the readings of the 20 dial thermometers. There was no indication that the relationship between the standard temperature and the temperature of the 20 dial thermometers was other than linear.

Temperatures indicated by the thermocouples averaged more than 1° below those of the standard thermometer except at the higher temperatures. The standard deviation of the 20 readings from the 20 thermocouples was about 0.2° to 0.3° F., showing good agreement among the readings. The normal accuracy of the recorder is 0.5°. The regression of the standard temperature (S) on the mean recorder temperature (R) was $S = 2.4 + 0.977\,R$.

There are several reasons why the thermocouple readings did not agree with the standard temperature readings. After this experiment had been completed it was determined that the thermocouple recorder was not adjusted accurately on scale, i.e., the recorder read 31.0° for a thermocouple placed in a melting-ice bath. After adjusting for scale reading at 32.0°, the span of the instrument was checked, and found accurate. Correct span means that the instrument is accurate at the upper and the lower end of the scale. In addition, the thermocouple temperature readings probably would have agreed with each other better than the standard deviations in Table 1 would indicate if the thermocouple junctions had been electrically insulated from the water in the bath. The thermocouples can be insulated from the surrounding medium with a substance such as glyptal paint.

The accuracy of the dial thermometers was checked under actual field conditions as well as in a water bath. Because the bimetal helix in the dial thermometer is about 1.5 inches long and placed near the tip of the stem, a point 1 inch from the tip of the stem was used as the point of depth reference in accordance with recommendations of Van Bavel and Forrest (5). In the case of field measurement, a small plastic dish about 4 inches in diameter was placed over the dial to protect it from hail and to prevent moisture from getting inside during rain. Soil temperature readings at a depth of 4 inches were taken daily at 8:00 a.m. with both glass and dial thermometers. Data from 10 paired glass and dial thermometers were obtained for 31 consecutive days.

The 31-day-average of temperature readings from the glass and dial thermometers as they were recorded in 10 plots and the average dial thermometer readings adjusted according to calibration in the water bath are given in Table 2. The data show that usually the agreement between the glass and dial thermometers is sufficiently close to make calibration of the thermometers and adjustment of data unnecessary. Occassionally it may be desirable to have a thermometer returned to the manufacturer for adjustment.

Table 2. Comparison of soil temperature as measured by glass and dial thermometers at a 4-inch depth at 8 a.m. for 31 days in a corn tillage experiment, June and July

Plot No.	Glass thermometer	Dial thermometer Unadjusted	Dial thermometer Adjusted[1]
		Degrees F.	
1	68.3	68.5	68.8
2	69.3	67.3	69.3
3	67.6	67.7	67.5
4	67.2	66.5	67.5
5	67.2	66.2	66.4
6	67.3	67.0	67.1
7	68.6	67.7	68.8
8	67.6	67.9	67.8
9	68.6	68.2	68.5
10	68.0	67.1	68.2

[1] Field readings corrected according to a calibration of the dial thermometers against a standard thermometer in a laboratory water bath.

Relation between the Daily Maximum and Minimum Soil Temperature and the Time of Day

For many biological studies an average daily soil temperature suffices. Usually this can be obtained most easily with maximum-minimum thermometers. However, if maximum-minimum thermometers are not available it is sometimes sufficient to approximate the daily maximum and minimum temperatures by reading glass thermometers at certain times of the day. The two experiments were concerned with (1) the effect of rates of mulch on soil temperature and (2) the effect of placement of residues on nitrogen transformations. Temperatures were measured at 2 and 4 inches in experiment 1 and at 0.25 and 6 inches in experiment 2. The data was not taken especially for this report. Rather the data was available and used here.

Temperatures at several soil depths in two experiments were recorded with the thermocouple recorder every hour on the hour at intervals throughout the summer of 1957. In each experiment temperatures were recorded from bare soil and soil mulched with 2 tons of cornstalks. Corn was grown in all experiments. The soil was Webster silt loam.

The time of occurrence of the minimum and maximum temperature at 0.25-, 2-, 4-, and 6-inch soil depths with and without a surface mulch is given in Tables 3 through 6. At the 0.25-inch depth the occurrence of the minimum temperature varied from 3 to 7 a.m. However, in about one-half of the cases the minimum temperature occurred at 5 a.m. The maximum temperature occurred from 11 a.m. to 3 p.m.; in nearly one-half of the days observed the maximum occurred at 12 noon. The presence of a surface mulch almost invariably did not influence the time of occurrence of the minimum or maximum temperature as shown by these data.

The median time of occurrence of the minimum and maximum temperatures at the 2-inch depth was 6 a.m. and 3 p.m., respectively. At both the 4- and 6-inch depths the minimum temperature occurred most frequently at 7 a.m. and the maximum at 5 p.m.

Graphs of the minimum temperature against the time at which the minimum temperature most frequently occurred and the minimum temperature versus the 8 a.m. temperature at various soil depths are given in figures 1 through 8.

Table 3. Time of occurrence of the minimum and maximum soil temperature at a 0.25-inch depth (data collected with thermocouple recorder).

Date	No Mulch		Mulch	
	Time of minimum temperature	Time of maximum temperature	Time of minimum temperature	Time of maximum temperature
1957	a.m.	m. or p.m.	a.m.	m. or p.m.[1]
6-5	6	3	6	3
6-6	6	-	6	-
6-17	3	2	3	1
6-18	5	1,2[2]	5	12
6-23	5	12	5	11 a.m.
6-24	5	2	5	2
7-9	5	1	5	12
7-10	5	12	5	1
7-18	5	12	5	12
7-19	5	12	5	12
7-26	5	3	5	3
7-27	5	1	5	1
8-3	7	2	7	2
8-4	6	-	6	-
8-13	5	12	5	12
8-14	5	12	5	1
8-23	6	3	5,6[2]	3
8-24	6	12	7	1
9-3	6	12	6	12
9-4	7	2	7	2
10-3	6	12	6	12
10-4	6	12	6	1
Median	5	12	5	12

[1] The hours are m. or p.m. except as noted.

[2] The temperature at the 2 times was the same.

Table 4. Time of occurrence of the minimum and maximum soil temperature at a 2-inch depth

Date	No Mulch		Mulch	
	Time of minimum temperature	Time of maximum temperature	Time of minimum temperature	Time of maximum temperature
1957	a.m.	p.m.	a.m.	p.m.
5-22	5	3	5	3
6-13	6	4	6	4
6-21	6	5	6	4
6-25	6	1	9	2
7-6	6	3	6	3
7-13	6	1	6	1
7-20	6	4	6	4
8-11	6	4	6	2
8-15	6	2	7	2
8-23	7	3	7	3
Median	6	3	6	3

Table 5. Time of occurrence of the minimum and maximum soil temperature at a 4-inch depth

Date	No Mulch		Mulch	
	Time of minimum temperature	Time of maximum temperature	Time of minimum temperature	Time of maximum temperature
1957	a.m.	p.m.	a.m.	p.m.
5-22	6	5	7	5
6-13	6	5	6	6
6-21	7	6	7	5
6-25	10	4	10	4
7-6	7	5	7	5
7-13	7	4,5*	7	4,5*
7-20	6	5	7	5
8-11	6,7*	5	7	6
8-15	7	4	7	4,5*
8-23	8	4	8	3
Median	7	5	7	5

* The temperature at the 2 times was the same.

Table 6. Time of occurrence of the minimum and maximum soil temperature at a 6-inch soil depth

Date	No Mulch		Mulch	
	Time of minimum temperature	Time of maximum temperature	Time of minimum temperature	Time of maximum temperature
1957	a.m.	p.m.	a.m.	p.m.
6-5	8	6,7,8*	7	8
6-6	7,8*	7	7,8*	8
6-17	6	6	4	5
6-18	8	4	8	5
6-23	7,8*	5	8	4
6-24	7,8*	6	7	5,6*
7-9	7,8*	5	8	5
7-10	8	5	8	6
7-18	6	5,6*	6	6
7-19	6	5	6,8*	5
7-26	6,7*	6	7	8
7-27	6	5	6	6
8-3	9	5,6*	7,8*	8
8-4	7	5	7	5
8-13	7	6	7	7
8-14	7	6	7	6
8-23	7	5	7	6
8-24	9	5	9	5
9-3	9	5	9	5
9-4	9	3	9	3
10-3	8	5	8	5
10-4	8	5	9	5
Median	7	5	7	5

*The temperature at the 2 times was the same.

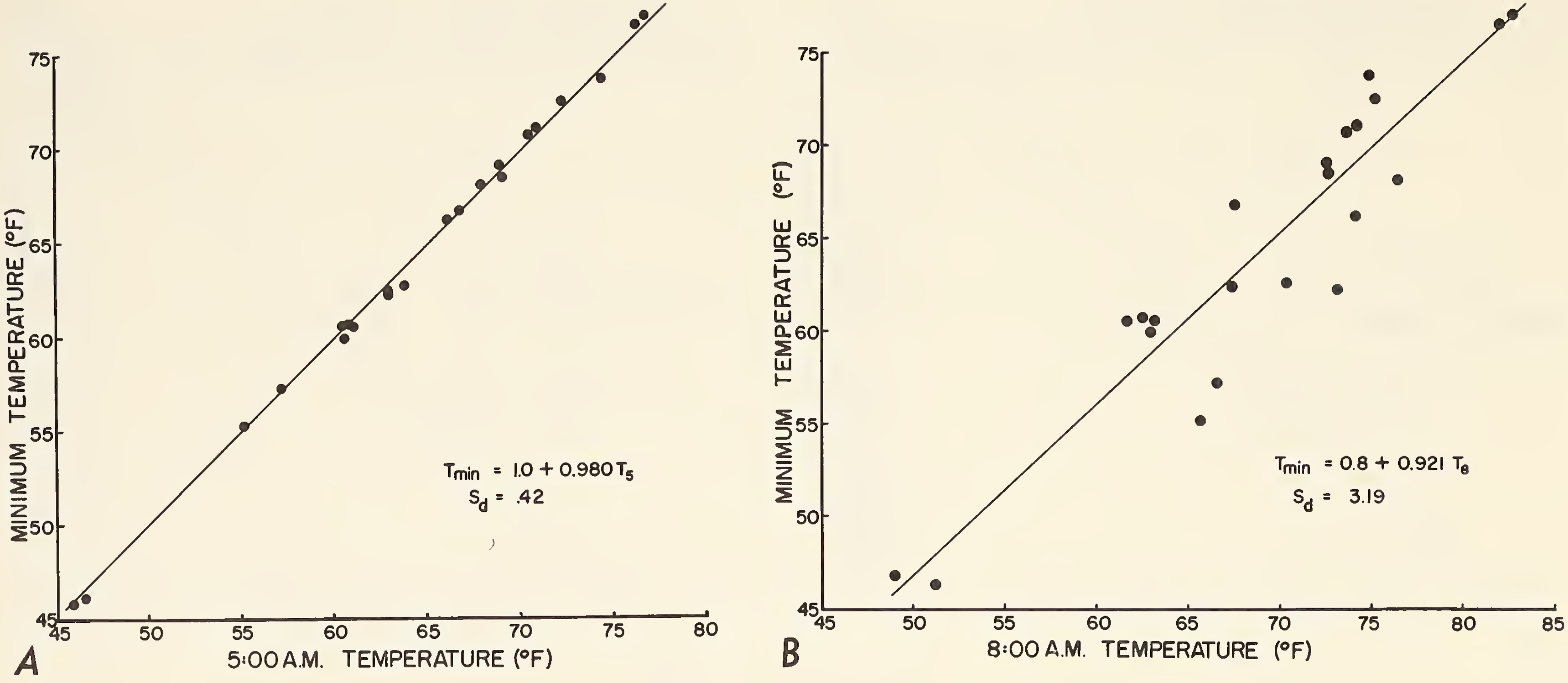

Figure 1.--Regression between the daily minimum temperature and A. the 5 a.m. and B. the 8 a.m. temperature at the 0.25-inch soil depth in a field of corn on Webster Silt loam at Ames, Iowa: (Each point is the average of 2 readings.)

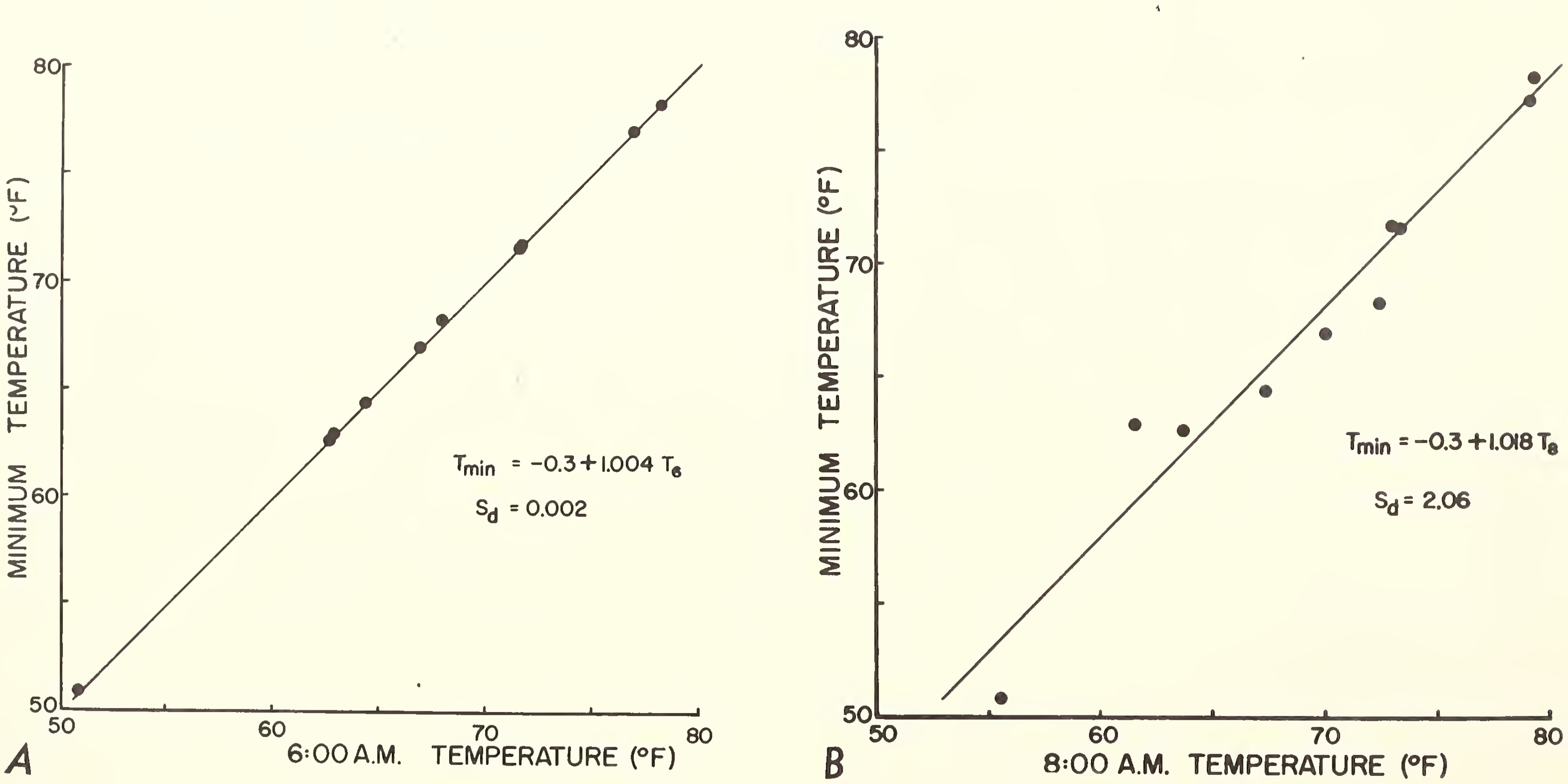

Figure 2.--Regression between the daily minimum temperature and A. the 6 a.m. and B. the 8 a.m. temperature at the 2-inch soil depth in a field of corn on Webster Silt loam at Ames, Iowa: (Each point is the average of 8 readings.)

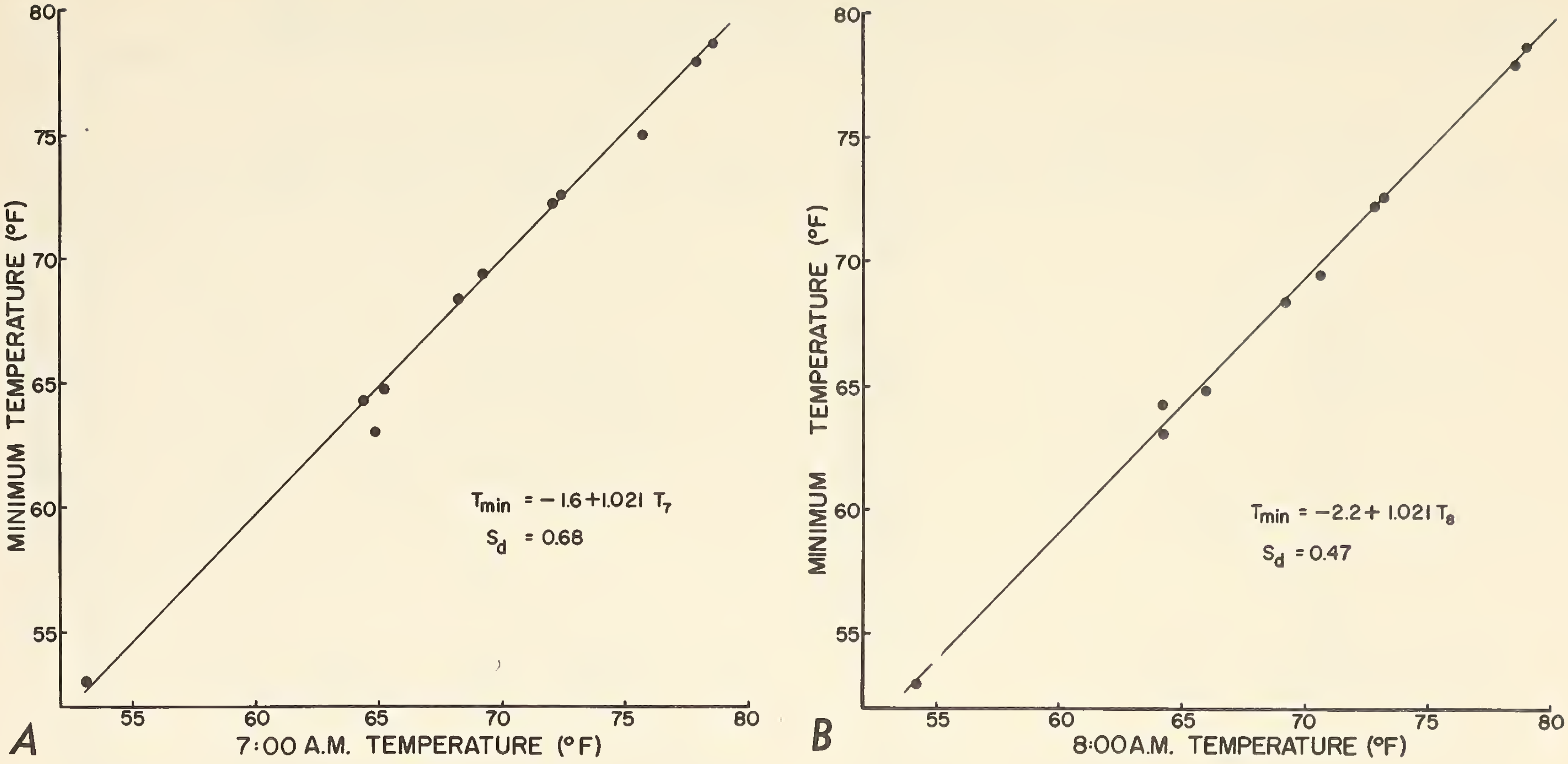

Figure 3.--Regression between the daily minimum temperature and A. the 7 a.m. and B. the 8 a.m. temperature at the 4-inch soil depth in a field of corn on Webster silt loam at Ames, Iowa: (Each point is the average of 8 readings.)

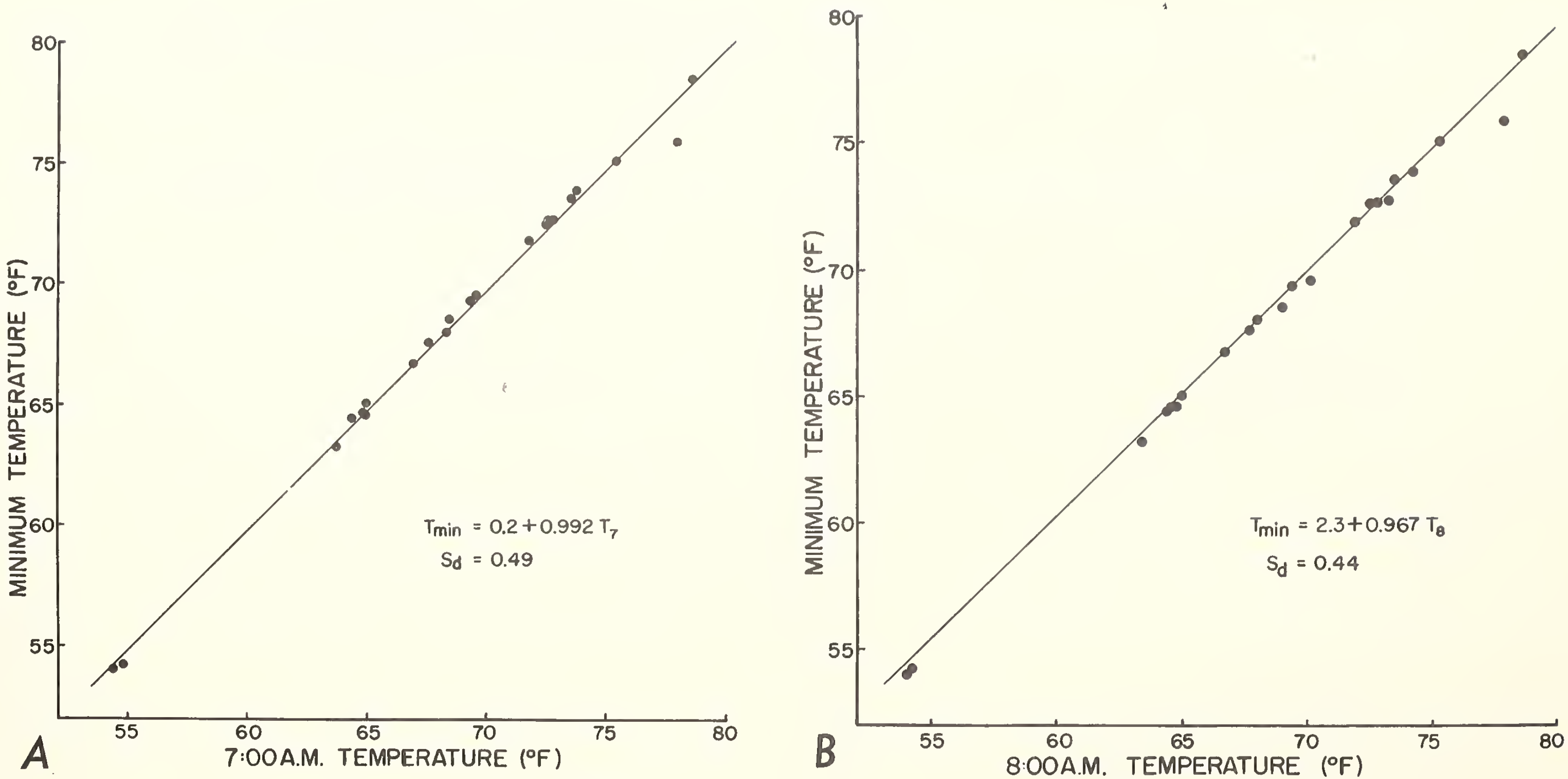

Figure 4.--Regression between the daily minimum temperature and A. the 7 a.m. and B. the 8 a.m. temperature at the 6-inch soil depth in a field of corn on Webster silt loam at Ames, Iowa. (Each point is the average of 2 readings.)

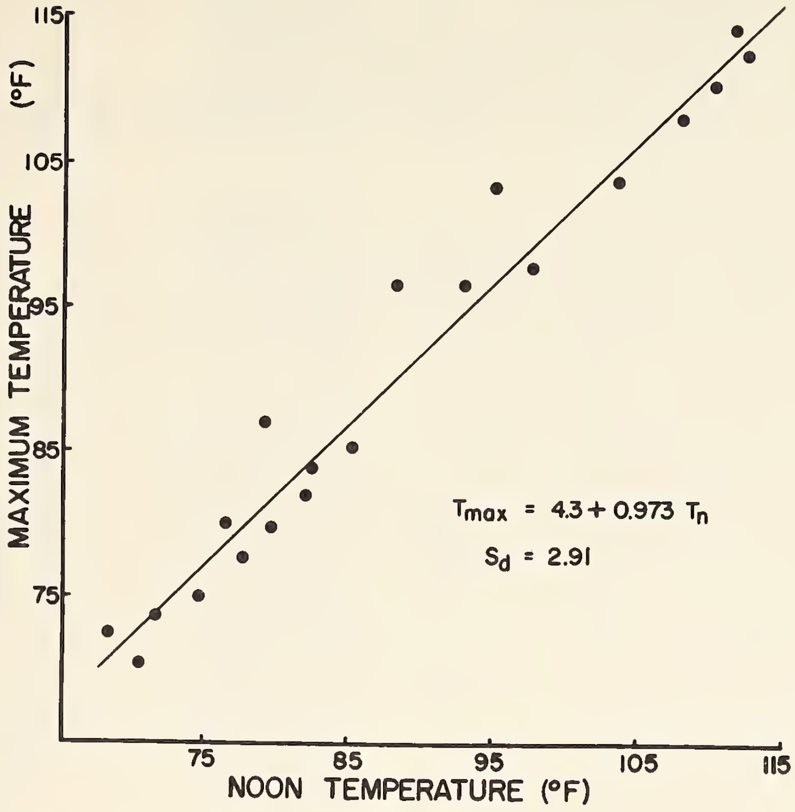

Figure 5.--Regression between the 12 noon and the daily maximum soil temperature at the 0.25-inch soil depth in a field of corn on Webster Silt loam at Ames, Iowa. (Each point is the average of 2 readings.)

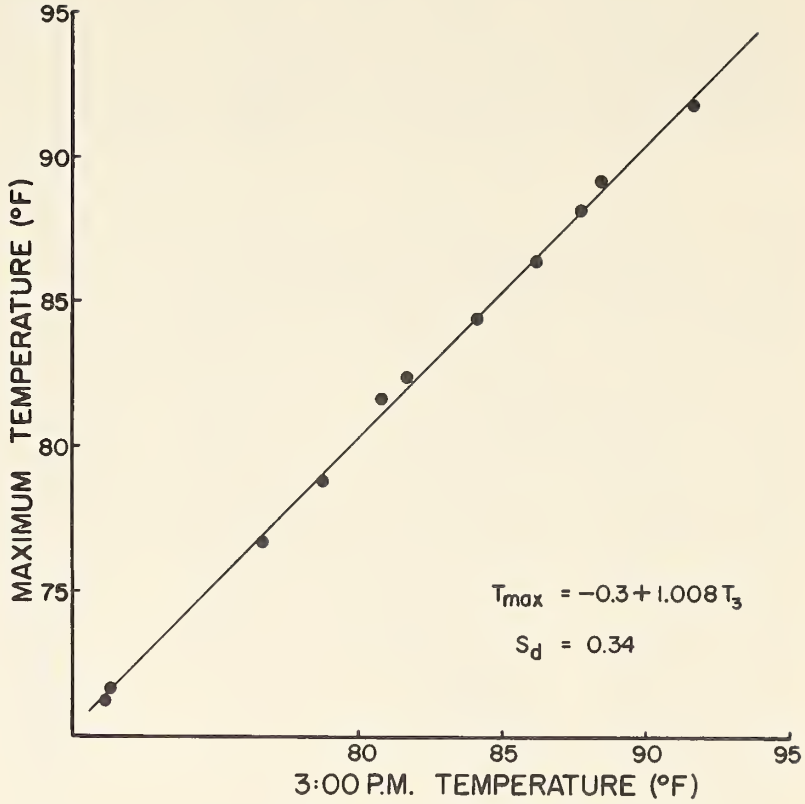

Figure 6.--Regression between the 3 p.m. temperature and the daily maximum temperature at the 2-inch soil depth in a field of corn on Webster Silt loam at Ames, Iowa: (Each point is the average of 8 readings.)

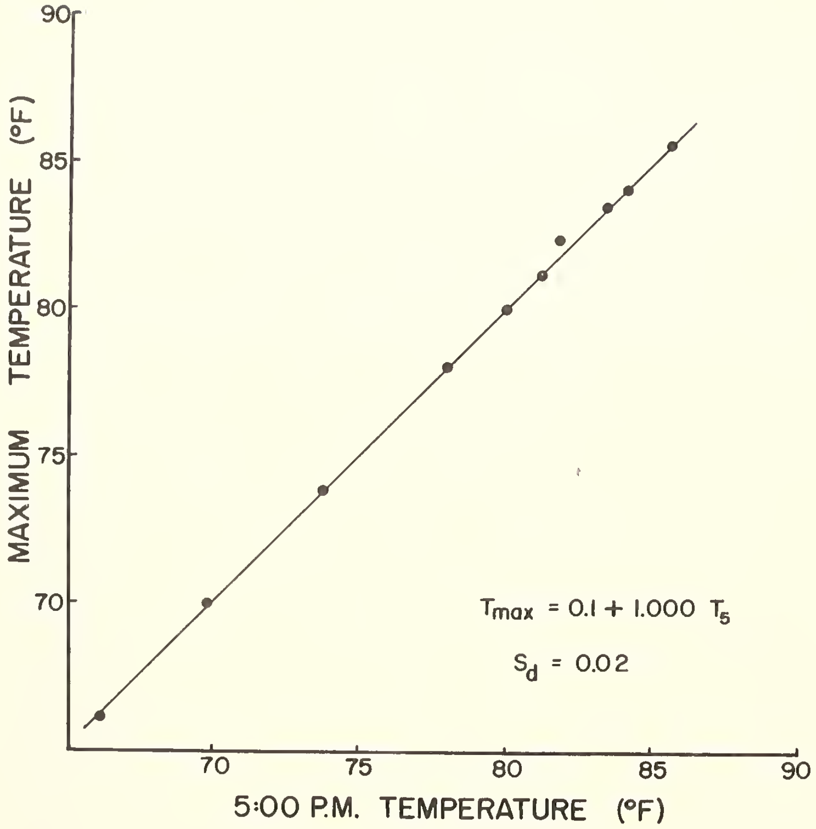

Figure 7.--Regression between the 5 p.m. temperature and the daily maximum temperature at the 4-inch soil depth in a field of corn on Webster silt loam at Ames, Iowa: (Each point is the average of 8 readings.)

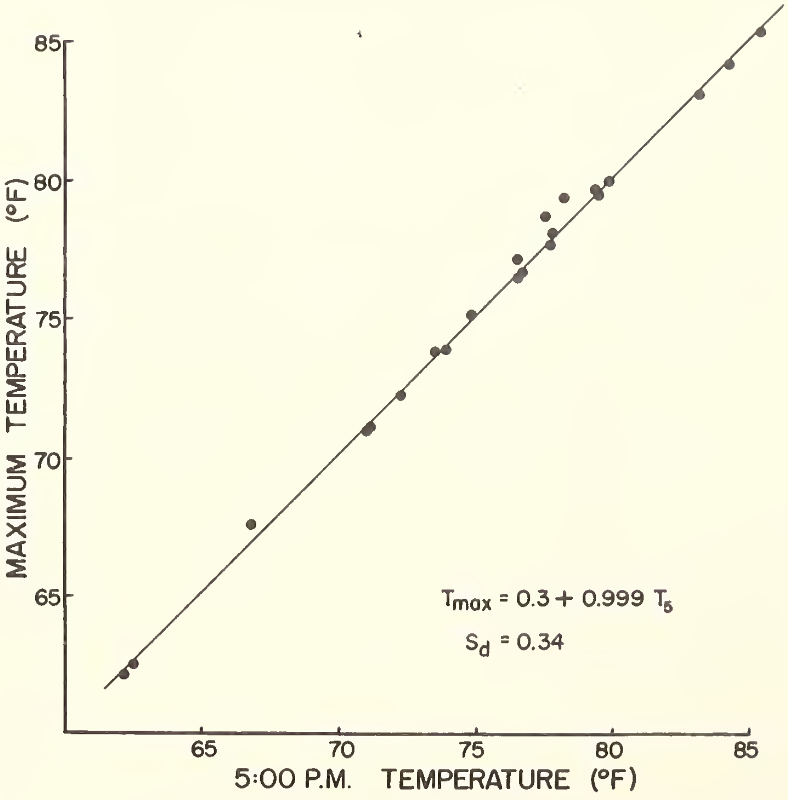

Figure 8.--Regression between the 5 p.m. temperature and the daily maximum temperature at the 6-inch soil depth in a field of corn on Webster silt loam at Ames, Iowa: (Each point is the average of 2 readings.)

The regression equation and the standard deviation[4] are also given. Because 8 a.m. is more convenient than earlier hours for reading thermometers, for all depths regressions between the 8 a.m. and the minimum temperature are shown. Graphs showing the minimum temperature for mulched soil versus the time at which the minimum temperature most frequently occurred are not included since they do not differ from corresponding graphs for unmulched soil.

The standard errors given in figure 1 through 4 show that the minimum temperature can be predicted rather accurately if a thermometer is read at the time at which the minimum temperature most frequently occurs. The standard errors are generally near 0.5° F., this indicates that for approximately two-thirds of the time the predicted minimum temperature was within 0.5° of the true minimum.

Based on regression of the 8 a.m. and minimum temperature, the predicted minimum did not agree well with the true minimum at the 0.25- and 2-inch soil depths. The standard deviation at the 0.25-inch depth was 3.19° F. and at the 2-inch depth was 2.06°. At the deeper depths the 7 and 8 a.m. temperatures were equally good for prediction of the minimum temperature.

Maximum temperatures plotted against the temperature at which the maximum most frequently occurred for the various soil depths are given in figures 5 through 8. The regression equation and the standard deviation are given. The relationship between the maximum temperatures and the noon temperatures at the 0.25-inch depth was not so close as would be desired for many studies, as indicated by the standard deviation of 2.91° F. At deeper depths the regression between the maximum temperature and the 3 p.m. temperature at the 2-inch depth and the 5 p.m. temperature at the 4-and 6-inch depts was close, as indicated by standard deviations of 0.35° or less. Thus it appears that at soil depths of 2 inches or more a close relationship exists between the maximum temperature and the temperature observed at the time the maximum most frequently occurs.

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[4] Calculated from the formula $Sd = \sqrt{\frac{s2}{n-2}(1 + 1/n)}$.

Each point in the figures represents the average of either 2 or 8 points. Analysis of covariance showed no significant regression in the "within days" term. Hence, the standard deviation is calculated from the regression of the average daily minimum temperature and the average daily temperature at the time of observation.

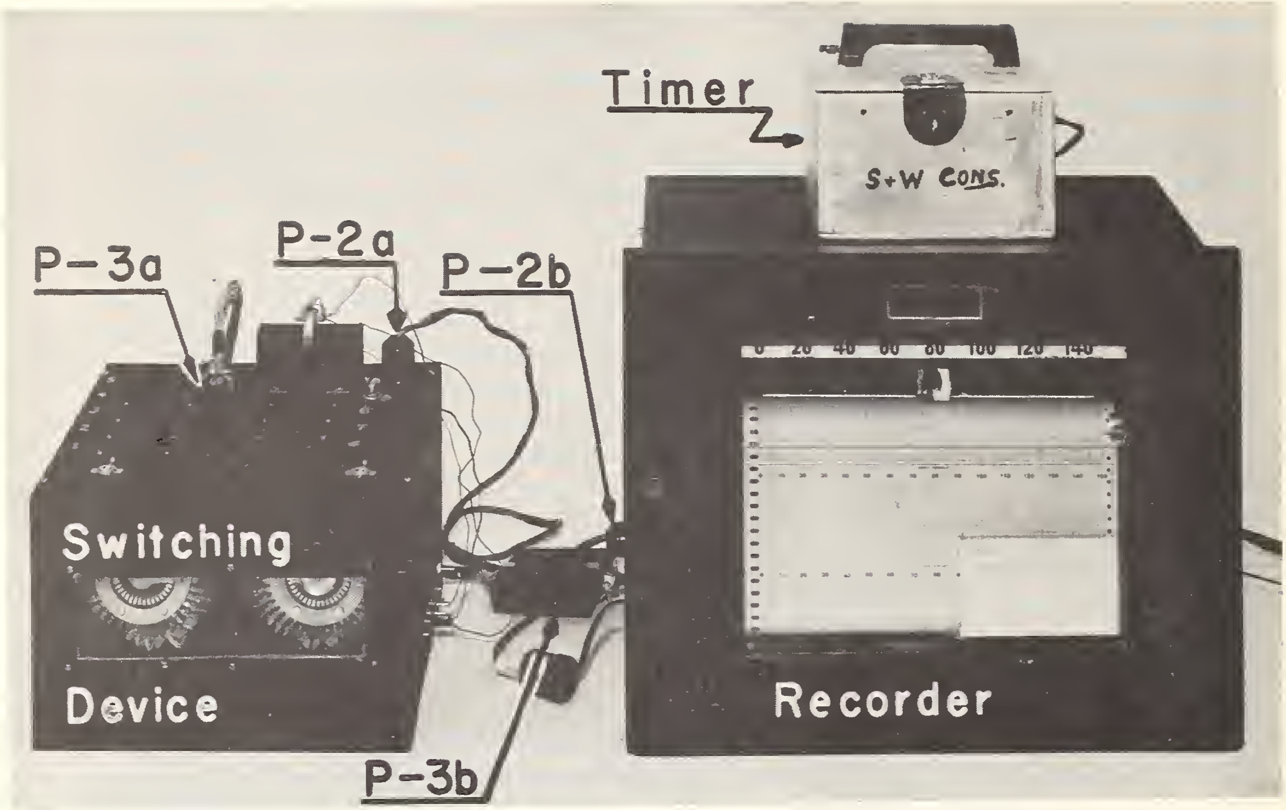

Figure 9.--Photograph of the complete recording unit.

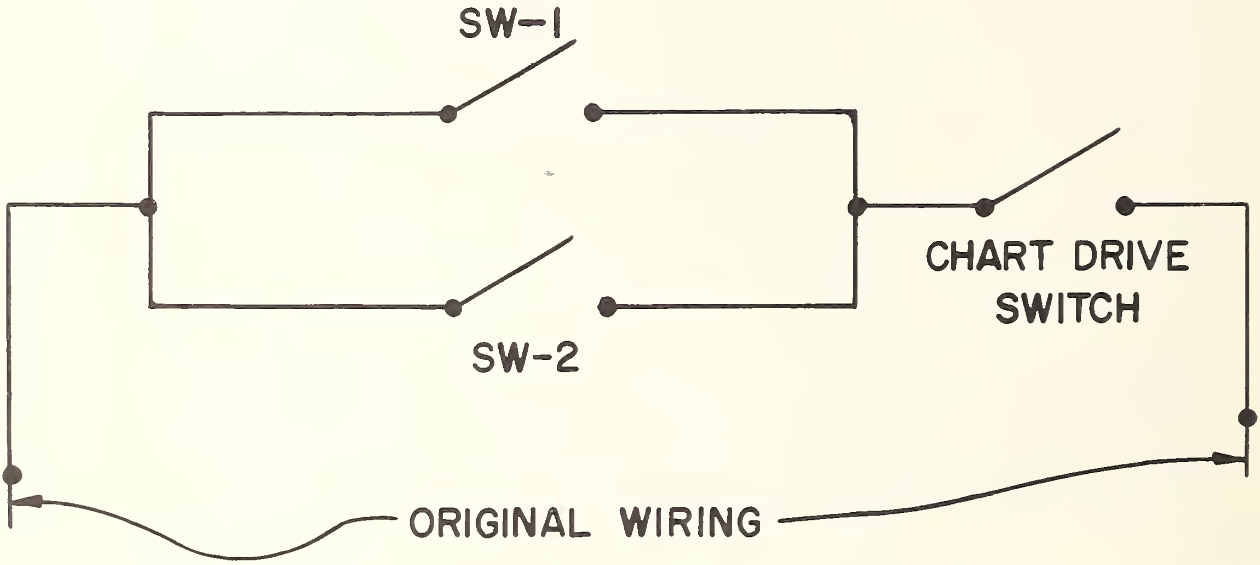

Figure 10.--Schematic diagram of the arrangement for starting a recording cycle.

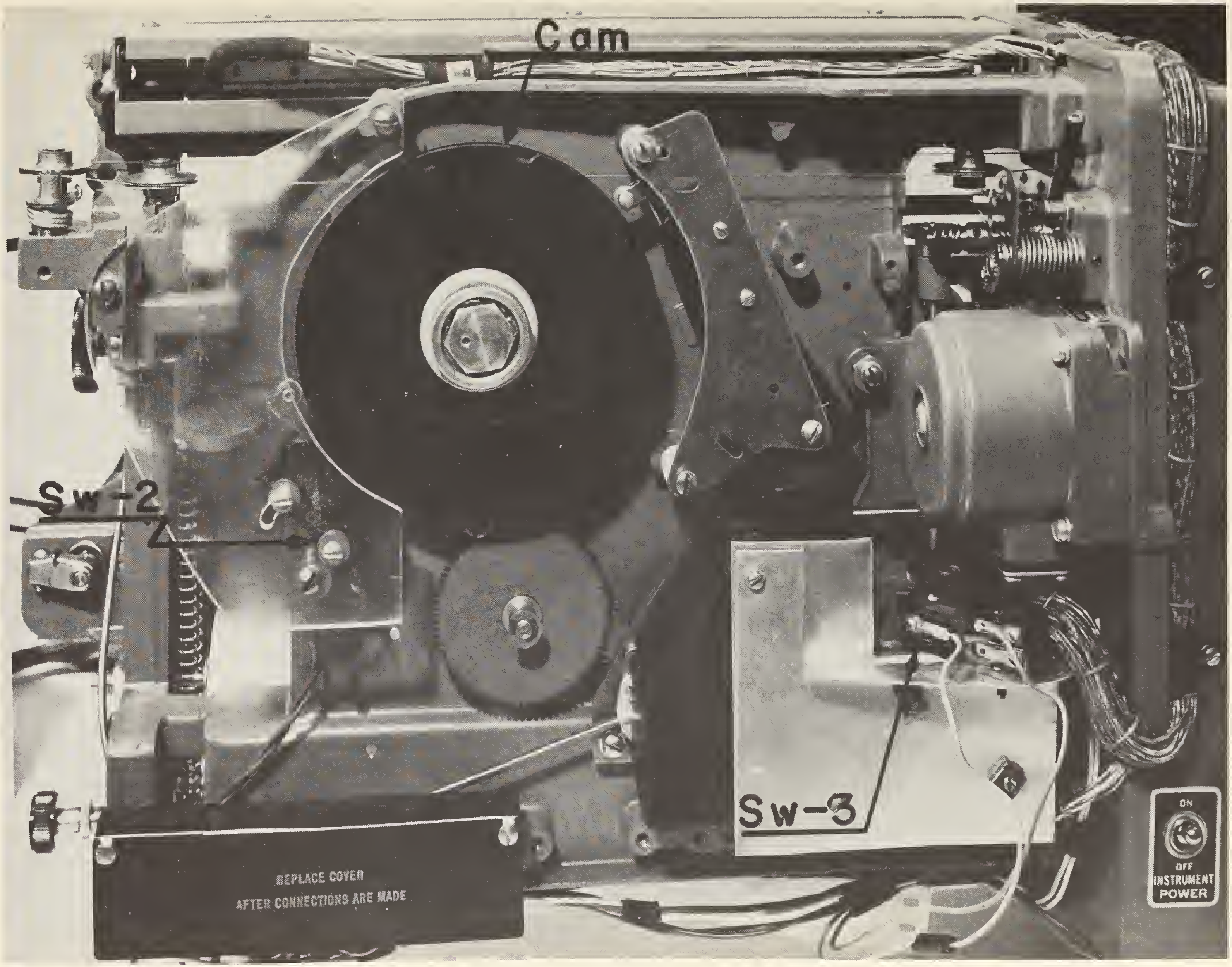

Figure 11.--Photograph of the rear of the recorder chassis.

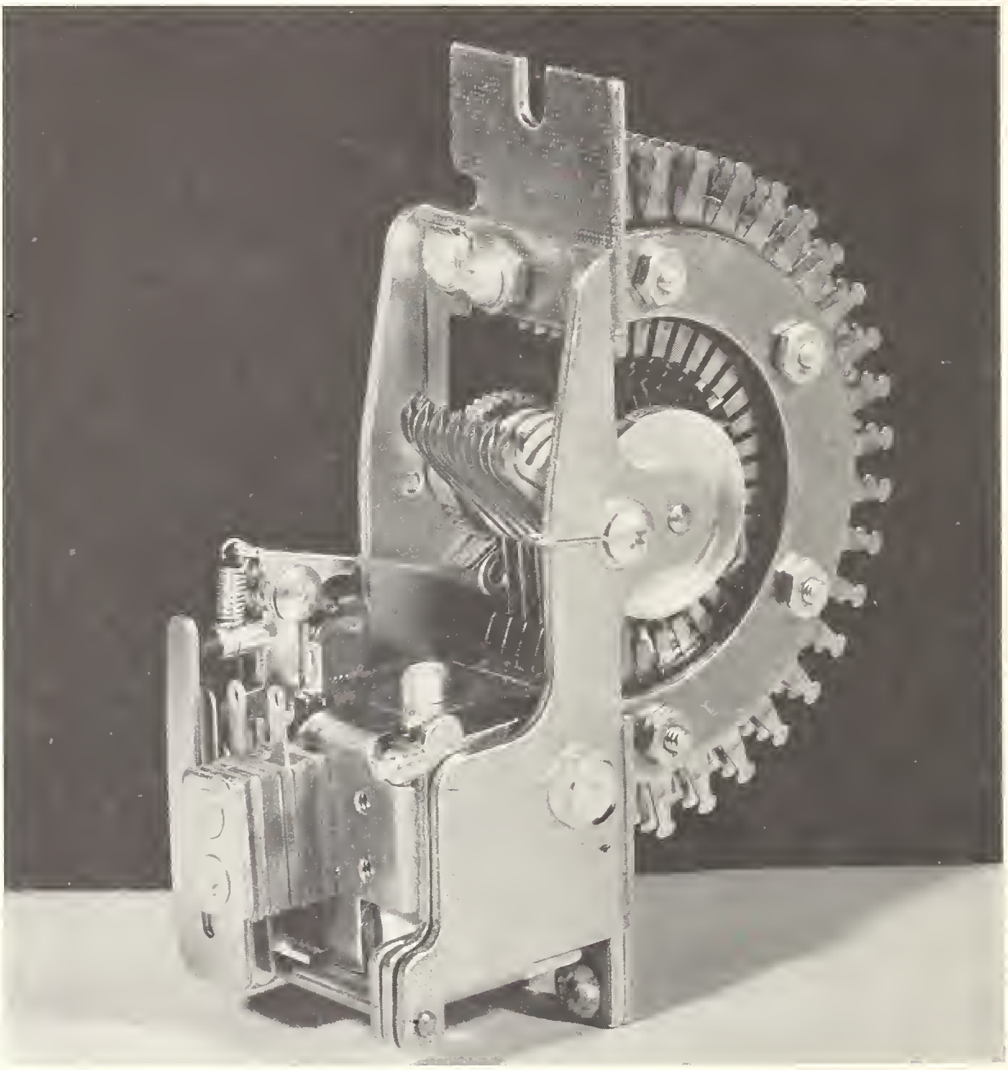

Figure 12.--Photograph of the stepping switch used in the switching device.

(Photo courtesy C. P. Clare and Company)

Discussion and Conclusions

The results of this study and others (1, 3, 5) show that glass thermometers, dial thermometers, and thermocouple recorders each have certain advantages and limitations for field measurements of soil temperature. The choice of instrument will depend on many things such as instrument cost, cost of labor, number of location measurements, frequency of measurement, accuracy required, and type of information desired. A list of the advantages, limitations, and points to consider for each of the three instruments is given below:

GLASS THERMOMETERS:

a. Are relatively accurate at depths below 1-inch.

b. Give a cheap instrument cost, but cost is high if frequent readings are required.

c. Can be moved easily over large plots.

DIAL THERMOMETERS:

a. Operate satisfactorily and are relatively accurate.

b. More costly than glass thermometers but saves on labor over glass thermometers.

c. Can be moved easily over large plots.

d. Give daily maximum and minimum temperatures with only one time of recording.

THERMOCOUPLE RECORDER:

a. Gives a precise measurement. In this study temperatures were greater than 1° F. below those of the standard at the lower range of the scale. However, if the recorder had been properly adjusted on scale and if the ground-thermocouple junction had been eliminated, the accuracy would undoubtedly have been improved.

b. Gives a large initial cost but will save on labor if a large number of readings are desired. In addition to the cost of the instrument the cost of wire will be considerable if the measurement points are some distance from the recorder. Also, if a recorder such as that described herein is used, the cost of chart paper, reading charts, and processing data is appreciable.

c. Requires plot size to be somewhat restricted since excessively long thermocouple lead-in wires offer too much resistance. This is not a problem in most experiments.

d. Requires a source of electrical energy (usually 110-volt a.c. line).

e. Is a sensitive instrument and requires almost daily attention.

The choice of the instrument will also depend on the type of information desired. Maximum, minimum, and average daily soil temperatures provide data from which degree-day and other growth indices can be calculated. In addition, if the thermal properties of the soil are known, estimates of heat conduction through the soil can be made. Multiple-point recorders will give a complete diurnal description of the soil temperature variations.

Instruments such as glass thermometers, which give soil temperatures only at the time of observation, can give comparable data between treatments but do not, unless read hourly or more often, produce data from which the daily soil temperature can be described. The primary source of energy for heating the soil is radiant energy from the sun. Because the radiant energy is greatest near noon one might expect soil temperatures at or near the soil surface to be greatest at noon or shortly thereafter. At deeper depths the time of occurrence of the maximum soil temperature will depend on the thermal conductivity of the soil. For most mineral soils, the maximum soil temperatures at the 2-, 4- and 6-inch depths will occur at about 2 to 4 p.m., 4 to 6 p.m. and 5 to 7 p.m., respectively (3). The observations in this study are in agreement with the times given above for occurrence of the maximum temperatures. Clouds (which intercept radiant energy), rainfall or rapid changes in air temperature may cause the time of occurrence of the maximum soil temperature to deviate considerably from the normal. Never-the-less the data in this report indicates that maximum soil temperatures at depths of 2-inches or more can be estimated with a standard error of about one-half degree from temperatures taken at the normal time of occurrence of the maximum. Near the soil surface, however, the standard error of the estimate of the maximum temperature from the 12 noon reading was 2.91°F.

Minimum daily soil temperatures near the soil surface would be expected shortly after sunrise since heat is normally lost from the soil to the air during the night whereas at sunrise the soil starts warming.

Because the thermal conductivity of most mineral soils with normal water contents does not vary widely, the daily minimum soil temperature in mineral soils at 2-, 4-, and 6-inch depths would be expected to occur about 1 hour, 2 hours, and 3 to 4 hours after sunrise, respectively (3). Again this is in agreement with the observations made herein. Because the time of sunrise varies during the growing season, it would be expected that the time of measurement of soil temperature for best correlation with the minimum would vary. For example, sunrise in central Iowa in mid-June is about 4:30 a.m. whereas in mid-September sunrise is about 6:00 a.m. However, because of limited data in this report the relationship between the minimum temperature and a constant clock time was equally as good as a constant time after sunrise.

Because of the variation of the thermal conductivity of the soil, the time of sunrise, normal cloud conditions, rainfall and soil moisture conditions, and many other soil, soil management and meteorological conditions the relationships between minimum temperatures, maximum temperatures and temperatures at specified times of the day given in this report should not be expected to apply to other geographical locations or possibly to other seasons. Rather they should be established for each experimental condition. The data in this report does not give a guide as to the accuracy of prediction of minimum or maximum temperatures from temperatures at specified times.

PART II. CONSTRUCTION OF SWITCHING MECHANISM

In soil temperature studies requiring large numbers of soil temperature observations, automatic recording mechanisms are by far the lowest cost method of gathering data. However, most commercial thermocouple recorders are built to record a maximum of about 20 temperature points from 20 thermocouples in one cycle. The instrument assembly described herein increases the number of points that a commercial thermocouple recorder will measure from 16 to 320. It is the purpose here to describe the construction and assembly of this unit. Similar switching mechanisms have been used for several years in farm structures research by the Agricultural Engineering Department of Iowa State College, Puckett (2) and Taylor (4) also have described similar instruments. The same principle is used in commercial devices, usually designed for specific applications. Flexibility, price, and availability of the thermocouple recorder were major factors in the decision to construct a unit rather than obtain a commercial instrument.

The basic parts of the complete unit are (a) a timing device to control the number of measuring cycles, (b) a multiple-point, strip-chart recorder, and (c) a switching device to increase the number of measuring points. For those interested in building such a unit, the basic parts are shown in figure 9 and are subsequently described in detail.

The timing device consists of a synchronous motor which makes 1 revolution per hour and a cam fastened on the motor shaft to activate a microswitch Sw-1[5] (see figure 10). The function of the timer is to complete a circuit for approximately 1 minute each hour. Any other time cycle may be used according to the application. Similar timing devices are commercially available.

Minor modifications of the recorder are necessary, for the reasons given below. None of these prevent the use of the recorder without the switching device and similar modifications can be made on other makes of instruments. Practically all of the recorders that measure temperatures by means of thermocouples are potentiometric devices. This means that they contain an operating battery and a standard cell, plus a mechanism for standardizing the operating battery voltage against the standard cell voltage. During this standardizing operation, the standard cell is directly connected into the measuring circuit. The recorder should not be turned off during the standardizing cycle since this will leave the measuring circuit complete and the standard cell can become completely discharged. In addition, since the amplifier requires a period of warm-up before the recorder begins to function properly, it is desirable to leave the amplifier on between cycles of measurement and turn off only that part of the recorder that controls the chart drive and print mechanisms. The first modification to be described gives the unit these desired characteristics.

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[5] The various switches will be labeled Sw-1, Sw-2, and so forth.

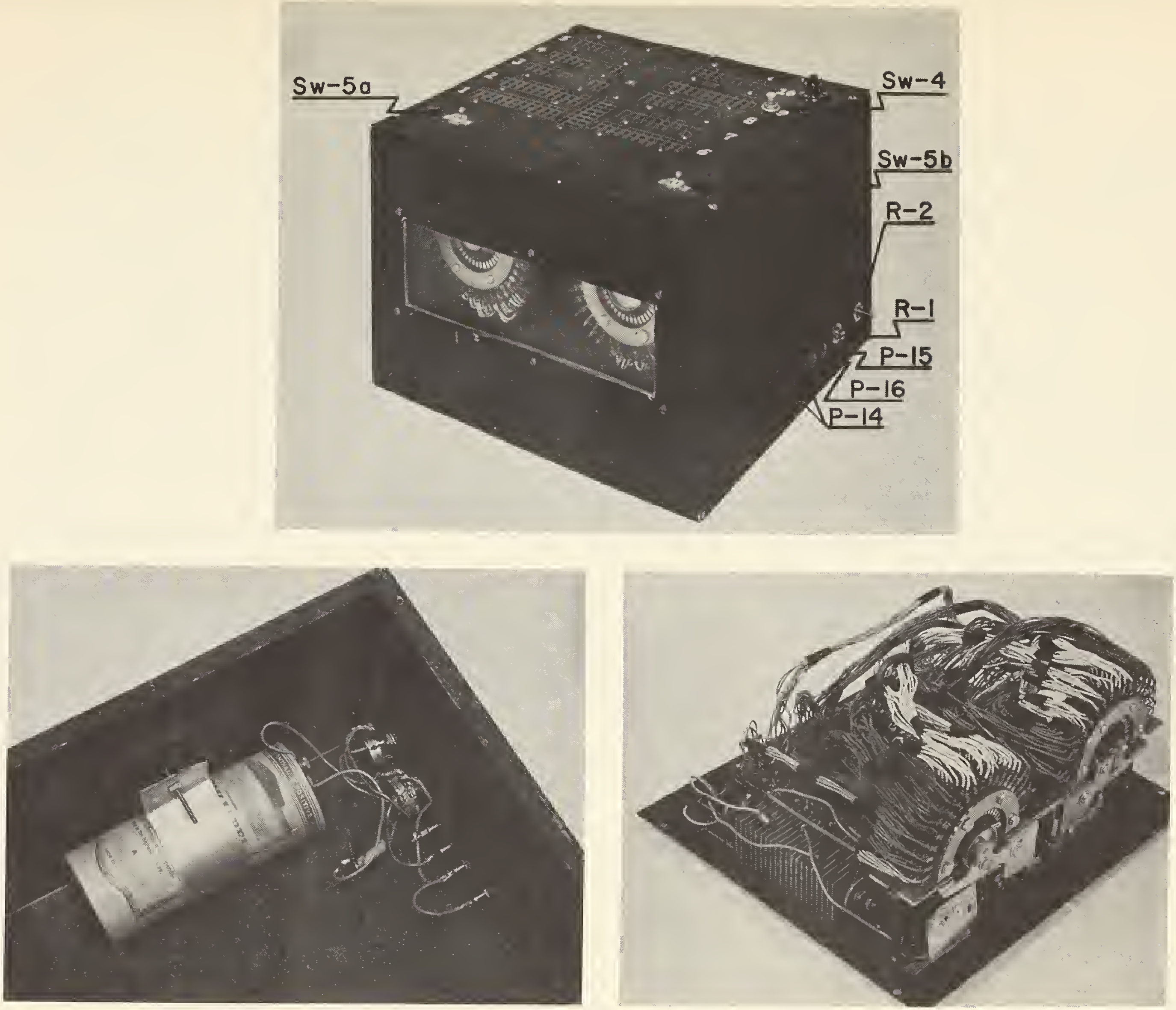
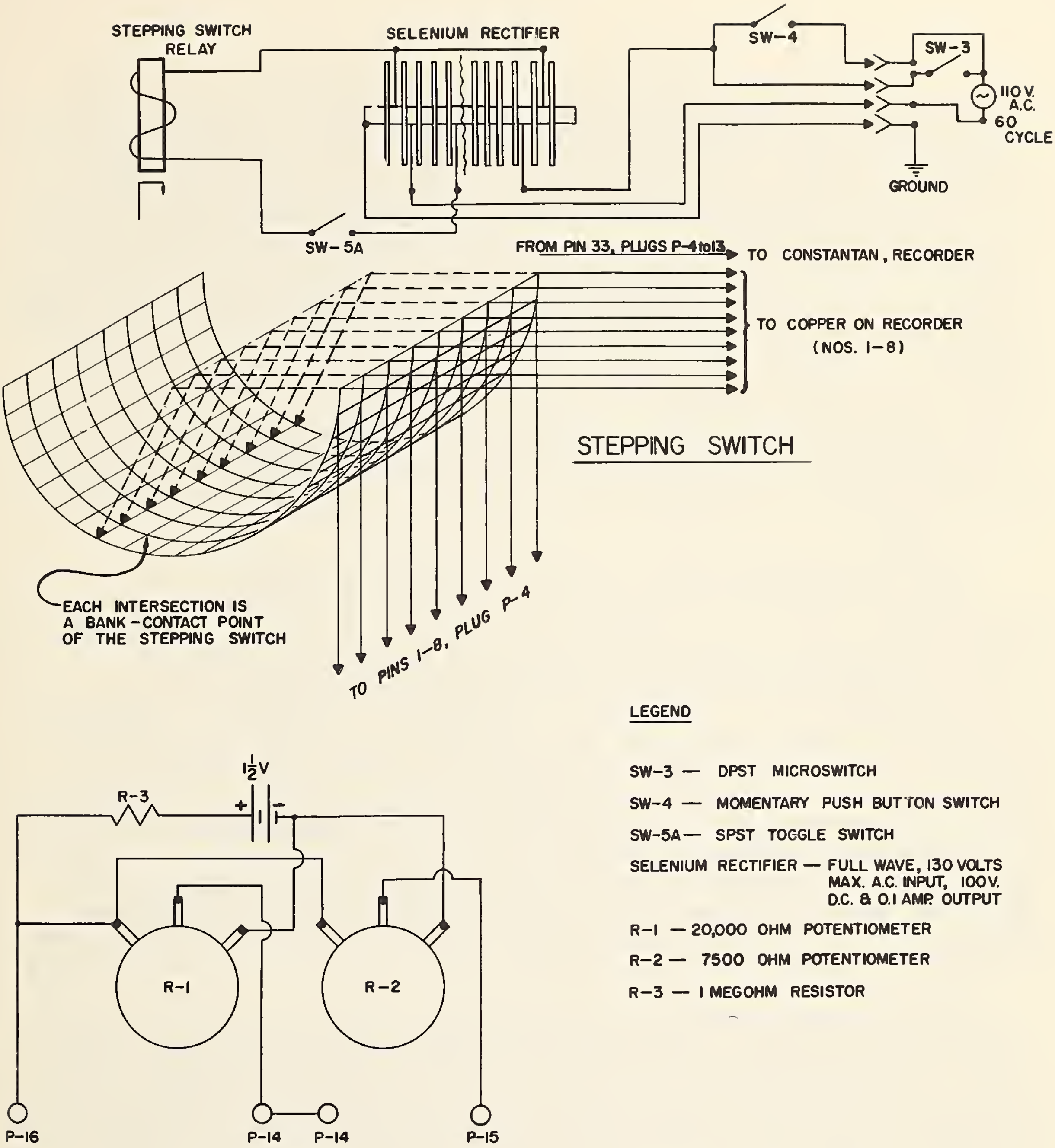


Figure 13.--Photograph of switching device.

At the bottom left of the front of the recorder chassis is the manually operated chart drive switch. The wire is removed from one terminal of this switch, and the switching shown in figure 10 is wired into this circuit. The microswitch Sw-1 is contained in the timing device that completes the circuit. The microswitch Sw-2 is operated by an extra cam placed on the indicator drive gear of the recorder. Figure 11, a photograph of the rear of a recorder chassis, shows this microswitch Sw-2 and cam in place. The cam, fabricated from 1/16-inch bakelite, has the same diameter as the cam already on the instrument except that an indentation is cut in the edge so that the microswitch roller will just fit. The microswitch Sw-2 is wired in the normally open position and placed so that the contacts are closed if the roller is not in the indentation on the cam. The cam is placed in position on the shaft so that the roller of the microswitch Sw-2 is in the indentation of the cam when the recorder indicator is in the farthest down-scale position. Thus, the amplifier remains on all the time and the chart drive and print mechanisms are operative only when the timer microswitch Sw-1 is on, or when the recorder is in an up-scale position.

At the end of each basic recording cycle, an impulse must be produced to activate the stepping switch so that the next set of contacts are connected into the recorder. Multiple point recorders are equipped with a rotating selector switch synchronized through a gear train with the print wheel; this selector switch provides the connecting electrical link between the potentiometer and the various thermocouples. On the recorder used herein the impulse is made by placing the microswitch, Sw-3 in figure 11, in position so that the existing index pin in the shaft of the selector switch closes the switch once every revolution (every basic cycle of the recorder). This energizes the relays of the spring-driven stepping switches. If not as many points are required only one stepping switch can be used, the only change in the arrangement being to lengthen the pin through the selector-switch shaft, thus giving the electrical pulse once every half cycle. This accordingly reduces the number of thermocouples one-half.

The switching device consists basically of two direct-current spring-driven stepping switches, such as the one depicted in figure 12, and a full-wave selenium rectifier to convert alternating current to direct current. As potentials involved in measuring temperatures with thermocouples are so small, the contacts of the stepping switches must be gold-plated in order to minimize contact resistance. The switch shown in figure 12 is a 20-step switch, each bank of contacts consisting of 8 levels of contacts, or 160 contacts in all. Thus, with 2 switches, each step would connect 1 bank of contacts from each switch for a total of 16 points. The plugs and sockets numbered P-2a and P-2b in figure 9 are for connecting the 110-volt supply between the recorder and the rectifier.



LEGEND

SW-3 — DPST MICROSWITCH
SW-4 — MOMENTARY PUSH BUTTON SWITCH
SW-5A — SPST TOGGLE SWITCH
SELENIUM RECTIFIER — FULL WAVE, 130 VOLTS MAX. A.C. INPUT, 100V. D.C. & 0.1 AMP. OUTPUT
R-1 — 20,000 OHM POTENTIOMETER
R-2 — 7500 OHM POTENTIOMETER
R-3 — 1 MEGOHM RESISTOR

Figure 14.--Semi-schematic wiring diagram for the switching mechanism.

A series of 33-pin polarized Jones plugs and sockets were used to connect the lead-ins from the thermocouples to the bank contacts of the stepping switches. The first 8 pins of the No. 1 socket are attached to the 8 bank contacts of the first step of the second stepping switch. Proceeding in this manner to the second step of each switch, then through the full 20 steps of each switch, 32 of the 33 pins on each of 10 Jones plugs are connected to the stepping switches. Pin No. 33 of each plug is reserved for a common constantan lead from each thermocouple. This common constantan lead and the 8 wiper contact terminals from each switch are connected to a 24-pin Jones socket also in the chassis of the switching device; from there a patch cord connects these leads to the recorder. The 24-pin Jones plug is numbered P-3a at the switching end and P-3b at the recorder end (fig. 9). The completed hookup of the stepping switches and other components of the switching device is shown in figure 13. The 33-pin Jones plugs are numbered from 1 through 10 on top of the switching-device case.

Since the recorder prints only the numerals 1 through 16, an indicator or marker point is needed at intervals throughout the cycle. The indicator points can be identified easily from the measuring points by connecting a potential from a 1 1/2-volt dry cell and rheostat (fig. 13) somewhat smaller or larger than the thermocouple potential to the indicator points. For example, if there are 6 points to be measured per plot in a field experiment, it is helpful to have the groups of 6 separated on the chart. This can be done by connecting the first 6 pins of the No. 1 Jones plug to the thermocouples from plot 1, pin 7 can be an indicator, pins 8 through 13 can be connected to thermocouples from plot 2, and pin 14 is the second indicator, etc. The potentiometer R-1 can be set so that the indicator points register a temperature approximately 20 degrees lower or higher than the temperatures being measured by the thermocouples, thus setting these points off on the chart for easy identification.

The shut-off mechanism is accomplished by connecting the dry cell (fig. 13) through potentiometer R-2, and plug P-15 to pin No. 31 of plug P-13. Potentiometer R-2 is then set so that a potential slightly less than the minimum scale reading is delivered. This will drive the recorder completely down-scale, thus turning off microswitch Sw-2 and completing the cycle. Pin No. 32 of the No. 10 Jones plug is connected to the indicator voltage so that a potential will be delivered at the beginning of the next cycle causing the unit to disengage the cam indentation.

While it is unnecessary to have all the 33-pin Jones plugs in place when using the instrument, Jones plug No. 10 is essential to the shut-off arrangement at the end of the cycle and must be in place at all times. In addition, pin No. 33 of this plug is the common constantan lead and is wired into plug P-16, thus completing the circuit for the indicator and cut-off mechanisms. A semischematic wiring diagram for the switching mechanism is shown in figure 14. Switch Sw-4 is a push-button-type switch used to step the stepping switches manually. Switches Sw-5a and Sw-5b disconnect each stepping switch individually from the stepping circuit so that either may be stepped alone.

The sequence of operations of the unit is as follows:

(1) On the hour the timer switch is turned on, letting the chart drive and print mechanisms operate.

(2) The recorder prints the cut-off point at the lower end of the scale and the next point provides the potential to drive the recorder up-scale, thus turning on switch Sw-2.

(3) The timer switch Sw-1 turns off, but the chart drive and print mechanisms remain on since the circuit is completed through Sw-2.

(4) The full cycle of points is recorded.

(5) The cut-off point is reached and the recorder is driven down-scale where Sw-2 shuts off the printing mechanism.

To prevent a current being induced in the thermocouple wire, care should be taken to see that no wire carrying 110-volt, 60-cycle alternating current passes along a wire carrying thermocouple potentials. As a precautionary measure, connect all metal parts, such as plug cases and the box containing the switching device to the grounded recorder chassis. In addition, chemical potentials and corrosion of the thermocouple junction may be prevented by dipping the bare thermocouple in glyptal paint. It must be remembered that the potentials produced by thermocouples are very small and thus any other potential is likely to give erroneous readings. For this reason, care should be taken to see that the plugs which connect the thermocouple lead-ins to the switching device are kept clean, and that all parts are commonly grounded to prevent induced stray potentials.

Parts List[6]

Number required	Designation	Approx. cost (each) Dollars	Possible source of supply
1	Strip chart Recorder Brown Model Number	1600.00	Brown Instrument Division, Minneapolis-Honeywell Regulator Corp.
2	Stepping switch, 20-step, 8-level, with gold-plated wipers and bank contacts.	70.50	C. P. Clare and Co. 3101 Pratt Blvd. Chicago 45, Ill.
1	Synchronous motor, 1 revolution per hour	5.75	Cramer Controls Corp. Centerbrook, Conn.
3	Microswitch, leaf-actuated, with roller, (Sw-1, 2, 3)	2.50	Microswitch Division Minneapolis-Honeywell Regulator Corp.
1	Cam, 1/16" bakelite		Locally fabricated
1	Switch, momentary-push button, SP (Sw-4)	.40	Any electronic supply house
2	Toggle switch, SPST (Sw-5a,b)	.40	Any electronic supply house
2	Potentiometers (R-1,2) (Similar to radio volume control), about 5-10 ohms resistance.	1.00	Any electronic supply house
1	Resistor, 1 megohm (R-3)	.59	Any electronic supply house
1	Selenium rectifier, full-wave, 110-v., a.c., input, 100-v., d.c. output at 0.1 amp.	12.00	Any electronic supply house
10	33-pin Jones plugs (cable-type plug, chassis-type socket) (P-4 through 13)	4.25	Any electronic supply house

2	24-pin Jones plugs (both plug & socket of cable type) (P-3a,b)	2.95	Any electronic supply house
2	Octal plugs and sockets (P-2a,b) (1 chassis-type plug 1 chassis-type socket 1 cable-type plug 1 cable-type socket)	.30	Any electronic supply house
3	Pin plugs and sockets (P-14,15,16)	.25	Any electronic supply house
1	Steel Cabinet (10" c 8" x 10")	3.50	Any electronic supply house
300 ft.	Thermoplastic insulated hook-up wire, #22 solid conductor (from stepping switch to Jones plug)	2.30	Any electronic supply house
50 ft.	Thermoplastic insulated hook-up wire, #18 stranded conductor (general use)	.80	Any electronic supply house
1	1 1/2-volt dry cell (for shut-off and indicator potential)		Hardware store
	Assorted nuts and bolts and washers for mounting the components		Hardware store
	1/32- to 1/16-inch aluminum sheet for mounting switches Sw-2 and 3		Hardware store

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6/ This information does not constitute endorsement of the product of any particular company, nor deny the possibility of superiority of other similar products.

LITERATURE CITED

1. Hamid, Quaiytum, and Shaw, Robert H. Measurement of soil temperature with laboratory mercury-in-glass thermometers. Iowa State College Jour. Sci. 30:243-247. 1955.

2. Puckett, H. B. Temperature measurement by remote control. Agr. Engin. 38: 242-243. 1957.

3. Shaw, Robert H. The measurement of soil temperature. Iowa State College Jour. Sci. 30:255-261. 1955.

4. Taylor, J. G. Multi-point recording. Instruments 25:1080-1081. 1952.

5. Van Bavel, C. H. M., and Forrest, L. A. An evaluation of dial thermometers for measuring soil temperature. U. S. Dept. Agr., Agr. Res. Serv. ARS 41-9. 1955.